F2013 ECE 6332 Project:
An Ultra Wide Band Design for Power Efficiency

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Exposing Communications Knobs at the System Layer

- Large optimizations found via high layer knobs that affect the lower levels
- We attempt to expose knobs related to communications theory at the systems layer that affect the lowest layers (circuit and device layers)
- We study power savings from turning these knobs
  - Compare a discrete knob: proposed Ultra Wide Band (UWB) technique vs. traditional Narrow Band (NB) technique

Knobs

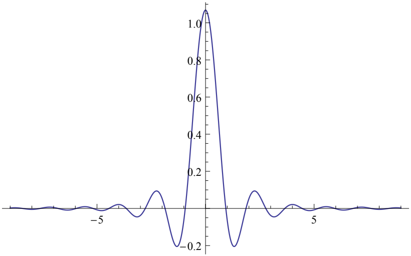
- Knob 1: Pulse shape
- Knob 2: Channel coding

Subdividing the Problem

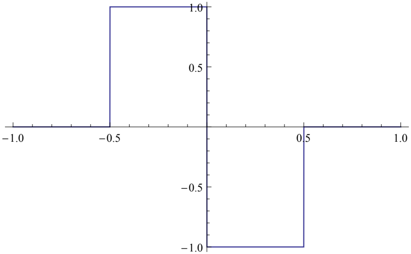
- Assume: transmitter power is constrained relative the receiver
  - Intuitively: Receiver has a larger power budget
- Example: Sensor networks with nodes that relay data to a host that can connect to the power grid
- Tradeoff space: Simpler transmitter $\rightarrow$ more complex receiver
- We study the transmitter with techniques used on the receiver, which is already well-understood

Knob 1: Pulse Shape

- Left: traditional NB pulse shape is the root raised cosine pulse
- Right: proposed Manchester pulse

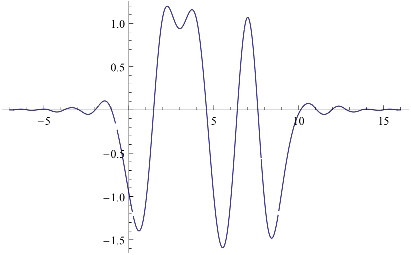


Root Raised Cosine Pulse

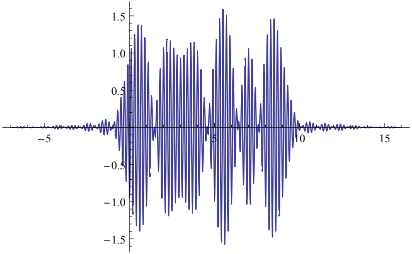


Manchester Pulse

Root Raised Cosine (RRC) Pulse Shaping

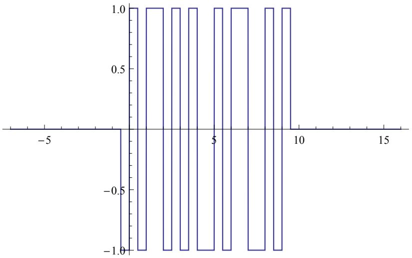


RRC Baseband



RRC Passband

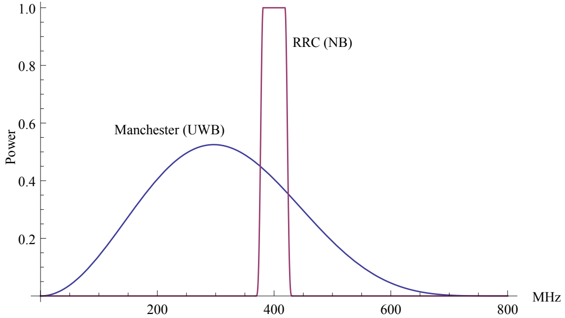
Manchester Pulse Shaping



Manchester Pulse Shaped Waveform

- Allows high efficiency switching power amplifiers (Class D,E, and F)
- Typical RRC-based amps have power efficiency around 50%
- Switching power amps have a theoretical efficiency of 100%

Ultra Wide Band Spectrum



Power Spectrum of UWB and NB

- FCC requires power density for UWB: -41.3 dBm/MHz
- Tranismit with Manchester pulses at 400 MHz, the maximum transmit power is $24\mu W$ or -16.2 dBm

Signal Processing Power Consumption

- Implemented key transmission functions in VHDL
  - We used the standard cell library included with FreePDK45
  - We used the standard voltage of 1.1 V for the FreePDK45 technology
  - We used a clock rate of 400 MHz which is necessary to generate the above UWB spectrum

Pulse Shaping Power Consumption

- Synthesized a 12-bit RRC pulse shaping circuit from VHDL
- Manchester pulse shaping is much easier:
  XOR the transmit bit sequence with the clock!

Pulse Shaping	Power Amp DC Power	Gates	Clock Speed	Processing Power	Timing Slack
Manchester	$24\mu W$	1	400 MHz	$453n\text{W}$	$19.96n\text{s}$
RRC	$48\mu W$	1132	400 MHz	$604\mu\text{W}$	$614p\text{s}$
RRC	$106\mu W$	1122	50 MHz	$498\mu\text{W}$	$18\mu\text{s}$

- Optimize narrow band system by lowering clock speed
  - shifts power from transmission
- New RF transmit power: $53\mu W$, which is only a 3.4 dB increase in power
  - not enough to make up for the loss in data rate by going to a higher order constellation

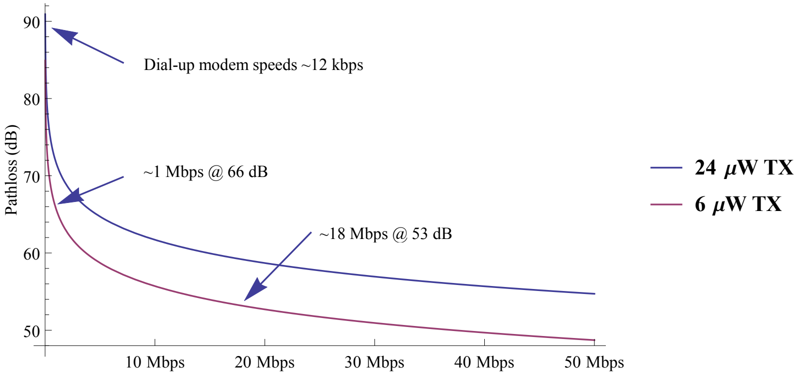
Knob 2:Channel Coding

- Channel coding provides a coding gain which provides reliability as well as the ability to lower the transmit power
- Synthesized a rate $1/8$ convolutional coder with constraint length 8
- Convolutional codes are not the most powerful codes known, but have a structure that can be implemented easily in hardware

Gates	Clock speed	Processing power	Timing slack
45	50 MHz	$30\mu W$	19 ns

- This code gives a coding gain of 6.5 dB at a BER of 10^{-5}
  - Equivalent to increasing the transmit power by 4.5 times
- It costs $30\mu W$ to implement, but gives an effect of increasing the transmit power from $24\mu W$ to $107\mu W$
- Use of channel coding in this scenario is a no-brainer
- Furthermore there is plenty of timing slack to reduce V_{dd} to save power

Pathloss Analysis



- Pathloss studies of body area networks show losses between 53 dB and 66 dB @ 2.4 GHz

Conclusions and Takeaways

- Manchester pulse shaping can save transmission power compared to Root-raised cosine shaping
  - Order of magnitude savings
  - Tradeoff: Increased receiver complexity
- Convolution encoding is power-efficient coding